Title: Practical torso per-cooling reduces thermal strain during soccer-specific exercise in the heat but does not improve repeated sprint performance

Abstract

Context: Pre-cooling and mid-event cooling of the torso using cooling vests can improve exercise performance in the heat with and without physiological changes; however, the effect of such cooling during intermittent exercise in the heat is currently unknown.

Objective: To investigate the effect of torso cooling during intermittent exercise in the heat (35°C and 50% RH) on sprint performance and the physiological and perceptual responses to the exercise.

Design: A randomised and counter-balanced cross-over design with repeated measures analyses was used to compare groups.

Setting: Laboratory. Walk-in environmental chamber.

Participants: Ten male, non-heat-acclimated soccer players (25 ± 2 y, 1.77 ± 0.06 m, 72.9 ± 7.6 kg).

Intervention(s): Two 90 min (2 x 45 min periods separated by ~15 min seated rest in cool conditions (~23°C, 50% RH)) bouts of soccer-specific intermittent running in the heat – one with a cooling vest worn during the exercise (VEST) and one without a cooling vest (CON).

Main outcome measure(s): Peak sprint speed (PSS), rectal temperature (T_r), skin temperature (T_{sk}), heart rate (HR), rating of perceived exertion (RPE), and thermal sensation (TS) were measured every 5 min.

Results: Peak sprint performance was largely unaffected by the cooling vest. T_r, T_{sk}, HR, RPE and TS were unaffected by the vest during the 1st 45 min but T_r rose at a slower rate in

VEST (0.026 ± 0.008 vs. 0.032 ± 0.009 °C·min^{-1}). During the 2nd 45 min, T_r, T_r rate of rise, T_{sk}, RPE and TS were lower in VEST ($g = 0.55 – 0.84$) but mean HR was unaffected. Conclusions: Our data study shows that a cooling vest worn during soccer-specific intermittent running in the heat can reduce physiological and perceptual strain but does not increase peak sprint speed.

Keywords: cooling vest, ice vest, football, intermittent exercise, cryotherapy, hyperthermia

Introduction

Many major soccer tournaments are played in hot, humid countries and as a result soccer players are often required to perform prolonged, high-intensity, intermittent exercise in temperatures approaching and exceeding 30°C (e.g. 2016 UEFA European Championships, France; 2019 FIFA Copa America, Brazil; 2022 FIFA World Cup, Qatar). Playing in elevated temperatures such as these can pose a threat to health and impair high-intensity sprint and soccer performance[1-4] due to a greater actual[5;6] and perceived[7;8] thermal strain. Minimising the health risk and the reduction in performance observed in high ambient temperatures would be attractive to athletes and coaches and so interventions such as cooling garments that might reduce actual and/or perceived thermal strain are sought.[9;10]

Cooling before exercise (pre-cooling) can improve subsequent exercise performance and capacity in the heat, with and without physiological alterations;[11] however, pre-cooling interventions have varying degrees of practicality. Cooling vests, which are used by many elite sporting teams,[12] are one of the more practical pre-cooling interventions because they are ergonomically designed, portable, and cover a large surface area of the body but data regarding their effectiveness in practical scenarios are equivocal. Pre-cooling using cooling vests can lower core body and skin temperatures, reduce heart rate and improve the perception of task difficulty and thermal comfort[13-16] but not all vests offer a sufficiently prolonged cooling effect to induce such changes[16;17] and so cooling strategies applied *during* exercise may be an option to consider. Cooling vests worn during exercise (per-cooling) can improve exercise capacity during heat stress;[18-20] however, it may only effectively reduce physiological strain when the magnitude of heat stress is very high e.g. when encapsulated in a nuclear biological chemical suit.[19] Short-duration (~30 min) cycling capacity is improved in the heat when wearing a cooling vest[18] largely due to reductions in perceived, rather than actual, physiological strain; however, the effect of cooling during more prolonged intermittent exercise is unknown.

Soccer match per-cooling might be a practical, and effective way to maintain performance and minimise the health risks of competing in the heat.[21] It is not within the laws of soccer to wear a cooling vest during competitive match-play but if such garments were effective and safe they could be worn during warm-ups, training sessions, and non-competitive soccer games held in hot, humid conditions. The aim of the present study was to investigate the effect of a cooling vest worn during soccer-specific intermittent running in the heat on sprint performance and the physiological, perceptual responses to the exercise.

Methods

Participants

Ten physically active, non-heat acclimated (no exposure to temperatures > 25°C for at least 10 days prior to the study) male soccer players (at least two bouts of soccer-specific training and one 90 min soccer match a week) volunteered. The mean ± SD age, stature, and body mass of the ten participants were 25 ± 2 y, 1.77 ± 0.06 m, and 72.9 ± 7.6 kg respectively. Participants were fully informed of any risks and discomforts associated with the study before completing a health screen questionnaire[22] and giving their informed written consent to participate. The health screen questionnaire was completed prior to each laboratory visit and scrutinised by the investigators to ensure the health status of the participants had not changed. Participants abstained from alcohol and strenuous exercise 24h prior to all trials and arrived at the laboratory ~30 min before the commencement of the trial ~1.5 h after drinking 500ml of water and > 2 hours post-prandial. Adherence to these requirements was verbally verified prior to all trials and no violations were reported. The study was approved according to the procedures of the University's Ethical Advisory Committee.

Experimental procedures

Participants visited the laboratory on three occasions - one familiarization session and two experimental trials, one with a cooling vest (VEST) and one without a cooling vest (CON). Experimental trials were conducted in a randomised, cross-over order at the same time of day (± 30 min) and were at least 6 d apart. All trials took place in a walk-in environmental chamber (Design Environmental WIR52-20HS; Design Environment Ltd., Gwent, UK) controlled at a temperature of 35.1 ± 0.2°C and relative humidity (RH) of 50.2 ± 0.5%. During the familiarization trial participants performed repeated maximal sprints on a non-motorised treadmill (Woodway Curve, Vor DEM, Auf Schrauben, Germany) until they reported feeling habituated and then completed one 45 min block of a soccer-specific intermittent running protocol (see below for details). During each experimental trial participants completed two 45 min bouts of a soccer-specific intermittent running protocol performed on a motorised treadmill (Pulsar, h/p/cosmos, Germany) separated by 15 min of seated rest in temperate conditions (~23°C, 50% RH). Participants wore a soccer shirt, shorts, socks and trainers during each trial. In one experimental trial participants wore a commercially available cooling vest (see below) throughout each 45 min bout. Participants drank water *ad libitum* during each trial – the volume consumed was recorded. The drinks bottles were refrigerated initially and allowed to warm to room temperature during the trial. Body mass was recorded before and after each experimental trial and these data were combined with the fluid consumption data to estimate sweat loss and sweat rate.

Soccer-specific intermittent running protocol

Following the completion of a 10 min standardised warm-up (5 min at 8 km·h^{-1} followed by 5 min of self-selected stretching) participants completed a 90 min laboratory based intermittent running treadmill protocol designed to replicate the demands of soccer as used previously.[23] The exercise protocol consisted of two 45 min halves separated by a 15 min passive rest undertaken outside the chamber in comfortable temperatures (~20 °C). Each 45 min half consisted of three 15 min blocks of soccer-specific activity repeated consecutively. The proportion of time spent undertaking each activity, and corresponding treadmill speed, was as follows; 3.8 % rest (0 km·h^{-1}), 27.9% walking (4 km·h^{1}), 38.9% jogging (8 km·h^{-1}), 19.9% cruising (10 km·h^{-1}) and 9.8% sprinting (self-paced maximum effort). Walking, jogging, and cruising were performed on a motorised treadmill with a 1% gradient whereas the maximal sprint was performed on a non-motorised treadmill located adjacent to the motorised treadmill (transition time between treadmills < 10 s). The order, speed, and duration of each activity was as per Clarke et al.[23] with the following adjustments 1) the jogging and cruising speeds were reduced from 12 km·h^{-1} and 15 km·h^{-1} respectively following pilot work which demonstrated that the participants were unable to complete the original speeds; 2) the order of activities was altered to ensure that one sprint was performed every 5 min (i.e. sprints were performed as per Figure 1 in the paper by Clarke et al. [23] with the following two changes – the 3rd sprint was the 10th rather than 11th action and the 7th sprint was the 27th rather than 26th action); 3) sprints were self-paced. The peak (PSS) sprint speed was recorded from every 5th min sprint.

Physiological and perceptual variables

Rectal temperature (T_r) was measured using a rectal thermistor (Grant Instruments (Cambridge) Ltd., UK) self-inserted ~10 cm past the anal sphincter. Skin thermistors (Grant Instruments (Cambridge) Ltd., UK) were attached to the participant using a transparent dressing (Tagaderm, 3M Health Care, USA) and water-proof tape (Transpore, 3M Health Care, USA) and mean weighted skin temperature (T_{sk}) was estimated using the weighted-mean of sternum, right forearm, right anterior thigh and right posterior calf temperatures using the equation of Ramanathan.[24] Heart rate (HR) was measured using a chest monitor (Polar Electro Oy, Kempele, Finland). Ratings of perceived exertion (RPE) was measured using a 6 (no exertion) – 20 (maximal exertion) scale[25] while thermal sensation (TS) was rated with a nine-point scale, ranging from 0 (unbearably cold) to 8 (unbearably hot) with 4 as comfortable (neutral).[26] The area under the curve (AUC) and rate of rise (ROR) was calculated for temperature data. Data were recorded at 5 min intervals.

Cooling vest

During the VEST trial, participants wore a commercially available cooling vest (Kewl Fit Performance Enhanced Vest [6626M-PEV], Techniche International, California, USA) while exercising. The vest was applied immediately after the warm up and was worn on top of the participants' soccer shirt throughout the first 45 min bout of exercise. The cooling vest was then removed at the start of the 15 min break and replaced with a new vest at the end of the break before participants re-entered the climatic chamber. The second vest was worn throughout the second 45 min of the trial. Each cooling vest had four pockets, covering both the anterior and posterior section of the torso, in which four sealed packets (378 g) of frozen phase-change cooling inserts (n-Hexadecane and n-Tetradecane) were inserted. The cooling vest with inserts weighed a total of 1,752 g. The vest covered 28.4 ± 1.8% of estimated body surface area (BSA) but not all of this was cooled - the activated phase-change cooling inserts covered approximately 8.3 ± 0.5% of the estimated BSA.[27]

Statistical analyses

Parametric data are presented as mean ± standard deviation and non-parametric data are presented as median [range]. For parametric data, two-way repeated-measure ANOVAs (trial x time or trial x half) were conducted to compare the differences in sprint data, HR, T_{re} and T_{sk} between the two trials (VEST vs. CON). Bonferroni post hoc tests were conducted to identify pair-wise differences when appropriate. Effect sizes (Hedges' *g*) were calculated to determine the magnitude of differences between trial pairings. For perceptual data, Friedman's ANOVA and Wilcoxon signed-rank tests were run and *r* effect sizes were calculated. The likelihood that the true value of the effect represents a worthwhile change was assessed using the following thresholds: $d < 0.2$ = trivial effect; 0.2 - 0.5 = small effect; 0.5 - 0.8 = moderate effect and > 0.8 = large effect, and $r = < 0.1$ = trivial effect; 0.1 - 0.3 = small effect; 0.3 - 0.5 = moderate effect and 0.5 - 0.7 = large effect, > 0.7 = very large effect.[28] For clarity, only moderate, large, and very large effects are reported and these are accompanied with mean differences and 95% confidence intervals. SPSS version 21.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. Statistical significance was accepted at the $p \leq 0.05$ level.

Results

Sprint performance

PSS data were similar between trials. There was no main effect of cooling ($p = 0.98$) or half ($p = 0.12$) nor was there a cooling by half interaction effect ($p = 0.84$) (Figure 1). PSS was higher in the 45th ($g = 0.71$; mean difference (95% CI) = 2.49 (0.25 – 4.72) $km \cdot hr^{-1}$) min but was unaffected at all other times.

Figure 1 about here

Physiological and perceptual variables

Physiological and perceptual data are reported in Figures 2, 3 and 4 and in Table 1. Pre-exercise T_r was similar in VEST (37.0 ± 0.2°C) and CON (36.9 ± 0.3°C) and T_r increased over time in both trials ($p < 0.01$). The ROR was greatest in CON in the 1st ($g = 0.67$, $p < 0.01$) and 2nd ($g = 0.75$, $p < 0.01$) 45 min bouts resulting in a lower T_r in VEST from 40 – 45 and 60 – 90 min (g = -0.54 – -1.26; mean difference (95% CI) range = -0.3 – -0.2 (-0.6 – 0.0)°C) (Figure 2). Mean T_r was not different in the 1st half but ROR and AUC were lower in VEST. The vest had a moderate effect on lowering mean T_r and T_r AUC for the second half and for the 90 min bout ($g = -0.68$, $p = 0.14$, mean difference (CI) = -0.16 (-0.34 – 0.01)°C and $g = -0.94$, $p < 0.01$, mean difference (CI) = -0.99 (-1.34 – 0.64)°C·min^{-1} respectively).

Figure 2 about here

Pre-exercise T_{sk} was similar between trials (34.2 ± 0.7°C in both trials) and increased over time in both trials ($p < 0.01$). In the 1st half, the vest had no effect on mean T_{sk} ($p = 0.90$) or ROR ($p = 0.92$) resulting in similar AUC ($p = 0.83$). T_{sk} was lower in VEST compared to CON in the 2nd half ($p < 0.01$, $g = 0.51$) (Figure 3) but ROR and AUC were similar ($P > 0.05$).

Figure 3 about here

HR increased over time ($p < 0.001$) and was similar between trials overall ($p = 0.59$) and in the 1st ($p = 0.53$) and 2nd halves ($p = 0.72$) (Figure 4).

Figure 4 about here

Overall, median RPE and TS were lower in VEST compared to CON (RPE: 13 [6 – 18] vs. 13 [6 – 20], $p < 0.01$, mean difference (95% CI) = -0.9 (-2.2 – 0.3); TS: 5 [1 – 7] vs. 6 [3 – 8], $p < 0.01$, mean difference (95% CI) = -0.7 (-1.3 – 0.0)) largely due to reductions in the 2nd 45 min ($r = 0.52$, $p < 0.01$ for both) (Table 1). The cooling vest had no effect on RPE ($r = 0.16$, $p = 0.18$) or TS ($r = 0.06$, $p = 0.62$) during the 1st half.

Table 1 about here

Fluid balance

There were no differences between trials for pre-trial body mass (VEST: 72.9 ± 7.5 kg; CON: 72.9 ± 7.6 kg, $p = 0.50$) or fluid consumption (VEST: 0.71 ± 0.15 L; CON: 0.71 ± 0.16 L, $p = 0.88$). The VEST had a moderate effect on lowering sweat loss (VEST: 1.74 ± 0.26 L; CON: 2.10 ± 0.66 L, $p = 0.09$, $g = 0.68$, mean difference (CI) = -0.36 (-0.73 – 0.00) L) and sweat rate (VEST: 1.15 ± 0.17 $L \cdot hr^{-1}$; CON: 1.40 ± 0.44 $L \cdot hr^{-1}$, $p = 0.09$, $g = 0.68$, mean difference (CI) = -0.24 (-0.49 – 0.00) $L \cdot hr^{-1}$).

Discussion

To our knowledge this is the first study to investigate the effect of wearing a cooling vest during intermittent exercise in the heat. Sprint performance was largely unaffected by cooling – only the final sprint of the 1st half was improved. Wearing a cooling vest slowed the rate of rise in rectal temperature, without altering other physiological or perceptual variables, in the 1st half and lowered actual and perceived thermal strain during the 2nd 45 min bout.

The ability to sustain high-intensity, repeated sprints is a requirement for successful soccer performance; however, in elevated temperatures the ability to perform such activity is impaired.[2-4] Previous studies have reported that pre-cooling and/or mid-event cooling using cooling vests has little effect on high-intensity, intermittent exercise (Cohen's $d < 0.3$)[9;29;30] and that meaningful benefits are only observed when the vest cooling is supplemented with other cooling methods such as water immersion, ice towels, and ice packs.[30] Our data suggest that per-cooling using a cooling vest during high-intensity, intermittent exercise in the heat also has little effect on overall sprinting performance [deleted; however, it alters performance on a sprint-by-sprint basis]. The highest PSS of the 1st half was observed in the 45th min in VEST [deleted: but without the vest PSS decreased after] and in the 20th min [deleted: and so despite being higher] in CON [deleted: in the 25th min PSS was lower in the 40th and 45th min. These data] suggesting that participants in the VEST trial adopted a slightly different pacing strategy when asked to maximally sprint in the 1st 45 min – starting slower and finishing faster than in the CON trial. [deleted: The disruption in pacing remained evident at the start of the 2nd 45 min because PSS was improved in the period between the 40th and 60th min in VEST; however, this benefit was not sustained throughout.] The slight disruption may have been, at least in part, [deleted: se data were observed despite participants in the VEST trial running with an] due to the extra ~1.75 kg in mass worn during the VEST trial [deleted: . due to wearing the cooling vest] which would have increased the energy cost of the activity.[13] A performance benefit may have been observed if the CON group wore an uncooled vest rather than no vest; however, such a comparison would likely overstate any true benefit because wearing uncooled garments is not normal practice and can impair performance compared to cooled equivalents due to discomfort and a lack of physiological and perceptual benefit.[31] [deleted: Despite the lack of overall effect and the increased energy cost, a beneficial disruption in pacing strategy was observed and such a change could have obvious implications for successful soccer-performance because players are required to react and respond to changing demands throughout the 90 min match.] Previous data suggest that there is an inverse relationship between core body temperature and intermittent sprint ability;[6;9;15] however, in this study, PSS was greatest in the 90th min of the intermittent sprint protocol in both trials when core temperatures were at their highest (see Fig. 1 & 2). It is worth noting that it is not uncommon for participants to have a “spurt” at the end of self-paced activities when they know that no further efforts are required.[32]

The cooling vest lowered T_r for most of the protocol with the greatest half-specific differences being observed during the last 15 min of each half. Effect sizes were small for the first 25 min of the protocol possibly due to the short duration of time between applying the vest and beginning exercise (< 5 min). A longer pre-cooling period may have had a greater effect on lowering core body temperature; however, a longer, or more severe cooling intervention prior to exercise may raise T_r due to the after-drop phenomenon.[33] In the present study an after-drop was not observed, likely due to the relatively low magnitude and gradual cooling offered by the vests which avoided a pronounced vasoconstriction response although reductions in T_{sk} indicate that surface cooling occurred. Mean-weighted, rather than site-specific, T_{sk} was measured meaning that none of the thermistors were located under the vest. Mean T_{sk} was lower in the 2nd half in the VEST trial largely as a result of a greater reduction during the 15 min break resulting in a lower T_{sk} at the start of the 2nd half. In the two previous studies that investigated the effect of wearing a cooling vest during exercise T_r and T_{sk} were unaffected. The vests cooled a similar body surface area (~5% BSA;[18] ~8% BSA (current study); ~10% BSA[20]) so the different observations are likely to be due to different methodological approaches. Participants in the study conducted by Luomala et al.[20] wore the vest for ~45 min although the vest stopped cooling after ~30 min and so it is likely to have become insulative after this time-point whereas in the study by Cuttell et al.[18] participants only exercised for ~30 min. We observed the greatest differences after 30 min and minimised any insulative issues by removing the vest at the end of the 1st 45 min and replacing it with a newly cooled one at the start of the 2nd 45 min.

[deleted: The lower T_r and T_{sk} at the start of the 2nd 45 min may explain why participants started the 2nd half with faster PSS but the reasons may also have been perceptual.] Median RPE and TS were lower in VEST compared to CON largely due to reductions in the 2nd 45 min (1st half data were similar). [deleted: Reductions in perceived thermal strain can improve exercise performance with and without physiological alterations;[11;34] and] In this case, the perceptual data aligned with the physiological data – the greatest reductions in both actual and perceived strain were observed during the 2nd 45 min of the protocol. A lower TS has been reported previously in the cooling vest per-cooling literature[18-20] but reductions in RPE have only previously been reported in the encapsulated heat stress study.[19] Decreased perceived thermal state is an important regulator of prolonged self-paced exercise in the heat[35] and so it is likely that the benefit of per-cooling would be more pronounced using a protocol with more self-paced components and/or using a vest capable of causing a greater, or earlier, reduction in TS.

In conclusion, per-cooling using a cooling vest during intermittent soccer-specific exercise [deleted: alters the pacing profile of self-paced sprint exercise but] does not improve overall repeated-sprint performance at the environmental temperatures investigated in this study. Per-cooling can lower physiological and perceptual strain during such activity and so a cooling vest may be of assistance to soccer players undertaking training, warm-ups, and/or practice matches in the heat.

Limitations, future direction, and practical applications

The magnitude of cooling provided by the cooling vest was not measured and this is a common limitation of pre- and per-cooling literature.[11] Although it is likely that the skin temperature under the vest was lowered based upon previous research,[9;18] this variable should be measured in future per-cooling studies. In addition to measures of the cooling magnitude offered, future investigations should ensure that hydration status is more closely measured and matched between trials to ensure that the effect of cooling alone can be more effectively assessed.

The ability to sustain high-intensity, repeated sprints is a requirement for successful soccer performance but it is not the sole requirement. Players are required to execute soccer-specific skills and make complex decisions throughout a match and although there are some indirect data to suggest that cooling may improve such actions[36] this was not measured in the present study. A FIFA review suggested that soccer match per-cooling might be a practical, and effective way to maintain performance and minimise the health risks of competing in the heat[21] and while the current study offers some support for the health component of this suggestion (e.g. moderately lower thermal strain), more work is required focusing on per-cooling and soccer-specific skill performance e.g. passing, shooting, decision making.

Per-cooling the torso can reduce the physiological and perceptual strain experienced during intermittent exercise in the heat; however, it did not improve repeated sprint performance in the heat. It is possible that the lack or performance benefit may be due, at least in part, to the increased energy cost of running with the vest. The vest increased the load that the participants were carrying in the VEST trial by ~1.75 kg and this will have increased the energy cost of the activity. Arngrimsson et al.[13] investigated the effects of a heavier (~4.5 kg) vest worn during a warm-up and reduced running speed by ~0.8$\mathrm{km \cdot hr^{-1}}$ “to compensate for the extra metabolic work done… due to the weight of the vest” (p 1868). The extent to which the vest investigated increased the energy cost of the exercise is unknown and could have been determined using a third trial in which participants wore an uncooled vest of the same mass; however, comparing a cooled vest to an uncooled vest may overstate any performance benefit because athletes would not perform activity while wearing an uncooled vest and previous cooling literature than has compared cooled and uncooled garments has reported performance impairments.[31]

Despite the lack of performance benefit in the present study the reduction in physiological and perceptual strain would be of interest to coaches and athletes alike when trying to maximise training volume while in hot conditions while maintaining athlete well-being and comfort. A per-cooling reduction in physiological and perceptual strain would be particularly useful when athletes have little time to prepare for competing in the heat (e.g. a sudden fixture change or a sudden heat wave); however, per-cooling should be avoided if full heat adaptation is desired because heat acclimation/acclimatisation requires elevated thermal strain and a sufficient thermal impulse.

List of figures and tables

Table 1. Physiological and perceptual data from the 1st half, half-time, and 2nd half of the soccer-specific intermittent-sprint protocol with and without a cooling vest (Top row: mean ± SD. Bottom row: Mean difference (95% confidence intervals))

Figure 1. Peak sprint speeds during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean ± SD). Black bars = VEST; grey bars = CON. *g* = difference between trials (Hedges' g > 0.5).

Figure 2. Rectal temperature during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean ± SD). Square = VEST; Triangle = CON. *g* = difference between trials (Hedges' g > 0.5).

Figure 3. Mean-weighted skin temperature during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean ± SD). Square = VEST; Triangle = CON. *g* = difference between trials (Hedges' g > 0.5).

Figure 4. Heart rate during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean ± SD). Square = VEST; Triangle = CON.

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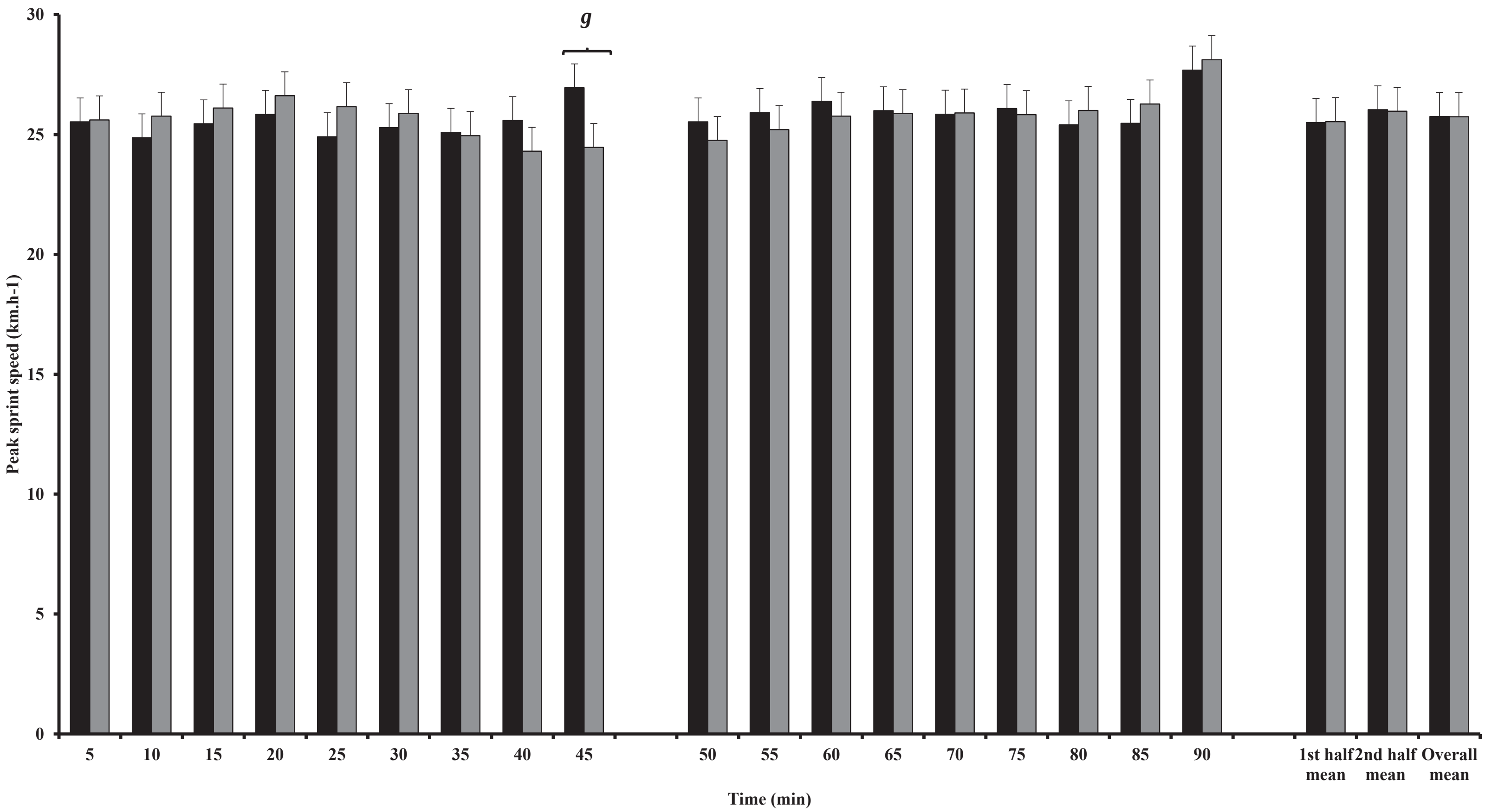
Table 1: Physiological and perceptual data from the 1st half, half-time, and 2nd half of the soccer-specific intermittent-sprint protocol with and without a cooling vest (Top row: mean ± SD. Bottom row: Mean difference (95% confidence intervals))

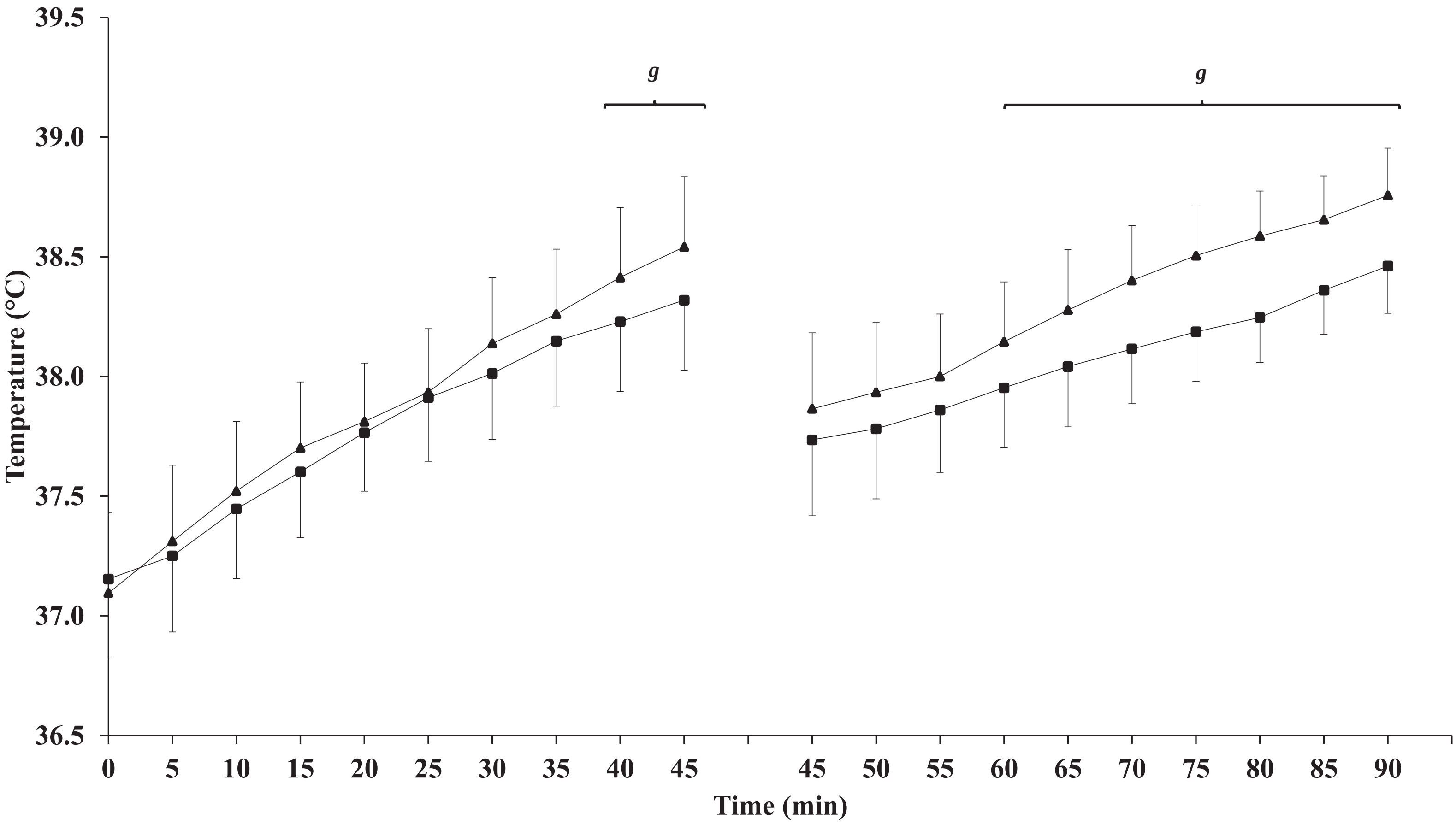
		1^{st} half		Half-time Δ		2^{nd} half	
Variable	Unit	VEST	CON	VEST	CON	VEST	CON
Mean T_r	°C	37.8 ± 0.2	38.1 ± 0.2	-0.6 ± 0.4	-0.7 ± 0.3	38.1 ± 0.2^{**L}	38.3 ± 0.3
		-0.09 (-0.28 – 0.1)				-0.24 (-0.46 – 0.01)	
T_r ROR	°C·min^{-1}	0.026 ± 0.008^{**M}	0.032 ± 0.009			0.017 ± 0.005^{*M}	0.022 ± 0.006
		-0.006 (-0.009 – -0.004)				-0.004 (-0.006 – -0.001)	
T_r AUC	°C·min^{-1}	3.1 ± 1.1^{**M}	3.6 ± 1.0			1.9 ± 0.6^{*M}	2.2 ± 0.7
		-0.64 (-0.87 – -0.41)				-0.35 (-0.64 – -0.06)	
Mean T_{sk}	°C	35.3 ± 0.6	35.2 ± 0.4	-2.9 ± 0.5 ^{*M}	-2.4 ± 0.8	34.7 ± 0.6^{**M}	35.0 ± 0.4
		0.01 (-0.20 – 0.21)				-0.34 (-0.51 – -0.16)	
T_{sk} ROR	°C·min^{-1}	0.035 ± 0.013	0.036 ± 0.012			0.056 ± 0.016	0.051 ± 0.022
		-0.001 (-0.005 – 0.004)				0.005 (-0.006 – 0.016)	
T_{sk} AUC	°C·min^{-1}	3.9 ± 1.4	4.0 ± 1.3			6.3 ± 1.8	5.8 ± 2.5
		-0.06 (-0.61 – 0.48)				0.58 (-0.66 – 1.82)	
Mean HR	b·min^{-1}	141 ± 16	137 ± 20	-55 ± 7	-51 ± 18	142 ± 14	141 ± 21

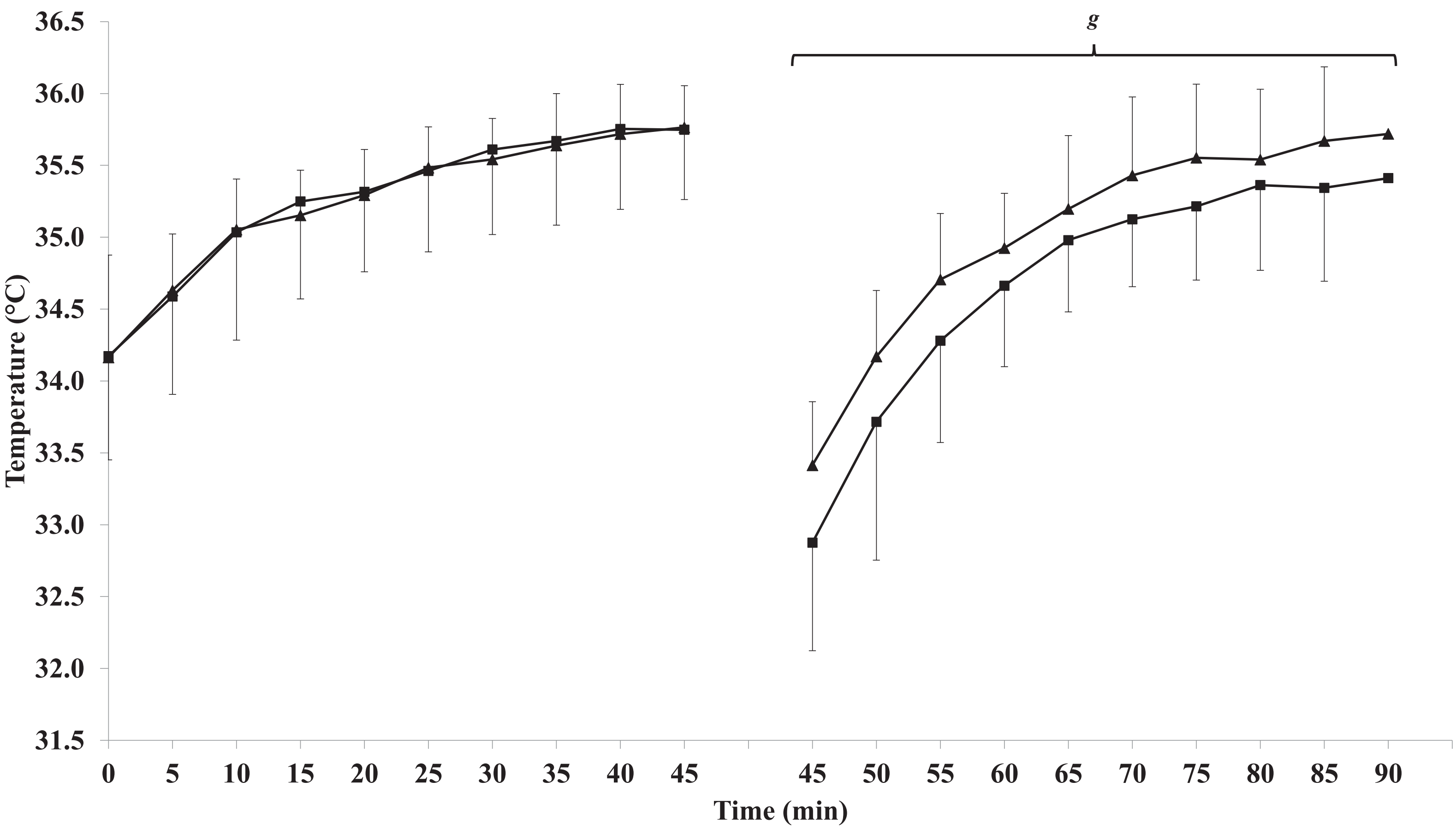
		4 (-7 – 14)				2 (-8 – 11)	
Median TS	AU	6 [3 – 7]	6 [4 – 8]	-2 [-4 – -2] ^{*M}	0 [-5 – 0]	5 [1 – 7]^{**L}	6 [3 – 8]
		0.1 (-0.7 – 1.0)				-0.7 (-1.3 – 0.0)	
Median RPE	AU	12 [6 – 15]	12 [9 – 16]			13 [6 – 18]^{**L}	14 [6 – 19]
		-0.2 (-1.3 – 0.8)				-0.9 (-1.9 – 0.0)	

Mean ± SD; Median [range]; T_r = rectal temperature; T_{sk} = mean weighted skin temperature; HR = heart rate; TS = thermal sensation; RPE = rating of perceived exertion (6 – 20); AU = arbitrary units; ROR = rate of rise; AUC = area under the curve; * = different from CON at the same time-point ($p < 0.05$); ** = different from CON at the same time-point ($p < 0.01$); ^{M} = moderate effect (d = 0.5 - 0.8; r = 0.3 – 0.5); ^{L} = large effect (d > 0.8; r > 0.5)

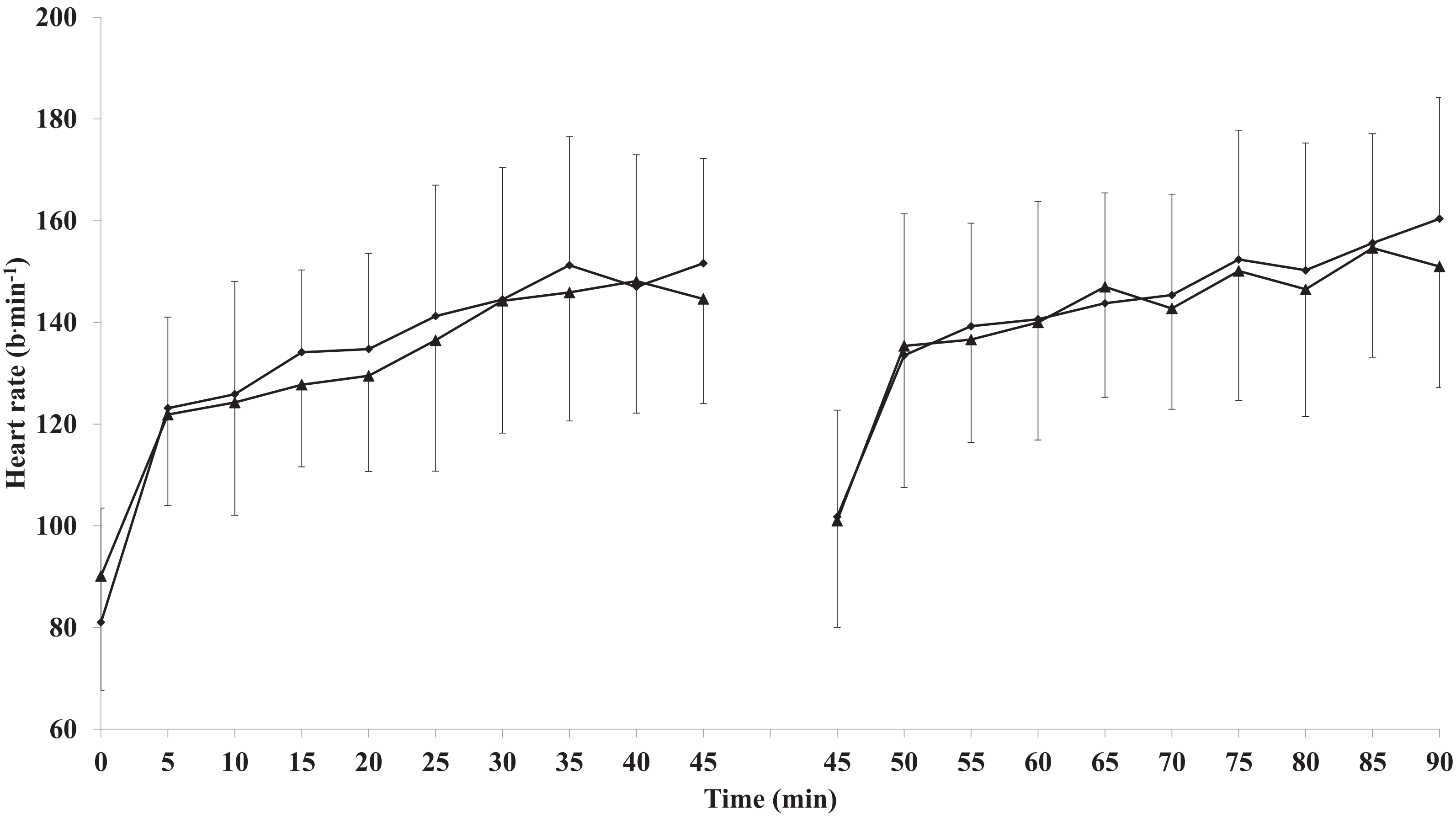


g
30
25
20
15
10
5
0
Peak sprint speed (km.h-1)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
1st half mean
2nd half mean
Overall mean
Time (min)


39.5
39.0
38.5
38.0
37.5
37.0
36.5
Temperature (°C)
g
g
0
5
10
15
20
25
30
35
40
45
45
50
55
60
65
70
75
80
85
90
Time (min)



g
36.5
36.0
35.5
35.0
34.5
34.0
33.5
33.0
32.5
32.0
31.5
Temperature (°C)
0 5 10 15 20 25 30 35 40 45
45 50 55 60 65 70 75 80 85 90
Time (min)


Heart rate (b·min-1)
200
180
160
140
120
100
80
60
0
5
10
15
20
25
30
35
40
45
45
50
55
60
65
70
75
80
85
90
Time (min)